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FULL LENGTH ARTICLE

Prediction of lycopene degradation during dehydration of watermelon pomace (*cv Sugar Baby*)

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KEYWORDS

Watermelon;
Pomace;
Lycopene;
Drying;
Thermal treatment;
Degradation kinetics

Abstract Lycopene retention in watermelon pomace during drying was investigated in fluidized-bed and cabinet dryer at 50–70 °C using 2–6 kg/m^2 tray loads. Page's model described the drying behaviour of watermelon pomace better than other models. Lycopene content of watermelon pomace dried in fluidized-bed dryer was 5.67–9.86 mg/100 g (db) whereas in cabinet dryer 4.82–8.12 mg/100 g (db) under experimental conditions. Lycopene retention was lower in cabinet dryer due to longer drying time. Degradation kinetics of lycopene in watermelon pomace followed first order model over 50–90 °C. Thermal degradation showed higher lycopene retention than drying under similar conditions of temperature and time indicating that circulating air increased the rate of lycopene degradation. Lycopene loss during drying of watermelon pomace was 19.02–60.57% whereas 7.46–43.28% was observed during thermal treatment of watermelon pomace. Fluidized bed dryer can be employed preferably over cabinet dryer to stabilize the watermelon pomace with higher lycopene retention.

1. Introduction

Watermelon (*Citrullus lanatus* Thunb) processing produced huge quantities of pomace which is major solid waste. The previous studies on watermelon reported 41.5–60% juice, 31–49.55% rind and 8.9–23.59% pomace (including seeds) on wet basis (Shin et al. 1978; Crandall and Kesterson, 1981; Uddin and Nanjundaswamy, 1982; Hayoglu and Fenercioglu, 1990; Sogi, 2003). Watermelon pomace is a concentrated source of lycopene containing more pigment than juice (Perkins-Veazie et al. 2006). Utilization of watermelon waste for pigment can reduce the problem of waste disposal and generate revenue. However, high moisture content of pomace makes it susceptible to microbial spoilage. Drying is a suitable technique to stabilize the waste which facilitates the pigment extraction.

Lycopene is a strong antioxidant, free radical scavenger and oxygen quencher. Watermelon flesh contains lycopene in the range of 3.9–7.8 mg/100 g which is about 60% more than tomato (Fish et al. 2001). Lycopene intake is associated with a decreased risk of various chronic cancers such as prostate, lung, breast, colon, pancreas, stomach, rectum, oesophagus, oral cavity, and cervix (Giovannucci, 1999; Bramley, 2000;

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Weisburger, 2002; Omoni and Aluko, 2005). Lycopene is in high demand by the pharmaceuticals industry as well as food and cosmetic industries (Borguini and Torres, 2009).

Lycopene is an unstable pigment that gets degraded by heat, light and oxygen through isomerization and oxidation (Schierle et al. 1997; Nguyen and Schwartz, 1999; Shi and Le Maguer, 2000). Degradation of lycopene affects the sensory attributes, health promoting ability and natural appearance of the food products. The present investigation was undertaken to study the drying behaviour of watermelon pomace and degradation of pigment during drying process.

2. Materials and methods

2.1. Material

Ripe watermelons of cultivar "*Sugar baby*" were procured from the Department of Vegetables, PAU, Ludhiana, India.

2.2. Separation of pomace

Watermelons were washed and cut into quarters by stainless steel knife manually. The rind of watermelon was removed, and flesh was separated from rind, cut into small pieces and passed through screw juice extractor (Kalsi Industries Ltd., Ludhiana, India) to get juice. The pomace was used for drying and pigment degradation studies.

2.3. Physico-chemical analysis of watermelon pomace

The moisture content of watermelon pomace was determined by drying it in a vacuum oven (Narang Scientific Pvt Ltd., New Delhi, India) at 60 ± 2 °C and 100 mm Hg pressure for 24 h. Total soluble solids were quantified by using Hand Refractometer (Model A, Erma, Tokyo, Japan). For the determination of ascorbic acid, the sample was extracted with metaphosphoric acid (30 g/L in water), filtrated and titrated against standardized 2,6-dichloroindophenol dye up to a pink colour end point, which persisted for 15 s. Crude protein and crude fat content were determined according to AOAC (1990). The pH and titratable acidity (as anhydrous citric acid) was determined using a pH meter (LI120, Elico, Hyderabad, India). Reducing and total sugars were determined according to Lane and Eynon method (Ranganna, 1986). Visual colour was measured using a Hunter colorimeter (Ultra Scan-VIS Hunter associates Laboratory, Reston, U.S.A.) in terms of L (lightness), a (redness and greenness) and b (yellowness and blueness).

2.4. Lycopene content

Sample (2 g) was extracted with acetone in a pestle and mortar till residues became colourless. Lycopene was transferred into petroleum ether phase by diluting acetone extract in a separating funnel, passed through sodium sulphate, volume made to 50 ml and absorbance was measured at 503 nm using UV visible spectrophotometer (2450 Shimadzu Co., Ltd., Tokyo, Japan) (Sadler et al. 1990). The extinction coefficient (17.2×10^4 mol cm^{-1}) was verified with standard lycopene solution (Sigma Chemical Co., St. Louis, Missouri, U.S.A.) and used to calculate the lycopene in sample.

2.5. Dehydration

Watermelon pomace was dehydrated in fluidized bed dryer (FBD 2000, Endecotts Ltd., London, U.K.) and cabinet dryer (ESS 36 T, La Parmigiana, Fidenza, Italy) at different temperatures 50, 60 and 70 °C with feed rates of 2, 4 and 6 kg/m^2. The initial weight as per tray load was considered at the mass at zero time. The change in weight was recorded after every 10 min and 1 h for fluidized bed dryer and cabinet dryer respectively. The drying was carried out till three concordant constant readings were obtained.

2.6. Mathematical drying models

The moisture ratio was calculated using the following equation:

$$\text{M.R.} = (m_t - m_e)/(m_o - m_e) \quad (1)$$

where M.R. – moisture ratio; m_t – moisture content dry basis (% db) at any given instant time t; m_e – equilibrium moisture content (% db); m_o – initial moisture content (% db); t – time (h).

The following mathematical models were applied to the drying data of watermelon pomace:

Lewis model $\text{M.R.} = \exp(-kt)$ (2)

Henderson and Pabis model $\text{M.R.} = a \cdot \exp(-kt)$ (3)

Logarithmic model $\text{M.R.} = a \cdot \exp(-kt^n) + c$ (4)

Page model $\text{M.R.} = \exp(-kt^n)$ (5)

Wang and Singh model $\text{M.R.} = 1 + at + bt^2$ (6)

where a, b, c, n, are constants in models (dimensionless number) and k is drying rate constant (1/h).

2.7. Effect of temperature on drying rate constant

The Arrhenius law can be used to relate drying rate constant with drying air temperature as follows:

$$k = k_o \exp(-E_a/RT) \quad (7)$$

where k_o – frequency factor (1/h); E_a – activation energy (kJ/mol); R – universal gas constant (8.314 kJ/mol K); T – absolute temperature (K).

2.8. Lycopene degradation during thermal treatment

The watermelon pomace was sealed in glass cultured tubes (19 mm internal diameter × 930 mm length) and was immersed in a water bath (TC-2000 Brookfield Laboratories, Middleboro, USA) for preset times (0–7 h) at 50, 60, 70, 80, 90 °C. The desired temperature was considered to have achieved when the temperature of water-bath reached the set value.

The kinetics of degradation of pigments has been reported to follow first order reaction adequately (Weemaes et al. 1999; Ahmed et al. 2000). The first order kinetic model for lycopene degradation is

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$$\ln(L/L_o) = -k_D t \quad (8)$$

where L is the concentration of lycopene at time 't' (mg/100 g), L_o is the initial concentration of lycopene (mg/100 g), k_D is the degradation rate constant (1/h), and t is heating time (h).

2.9. Lycopene degradation during drying

The best suited drying model was used to calculate the drying time needed to reduce the initial moisture content to 8.5% db. The degradation model was applied using calculated time for drying at 50, 60 and 70 °C and compared with experimental data.

2.10. Statistical analysis

The parameters were estimated by fitting the mathematical model to experimental data, using nonlinear regression. The adequacy of fitted function was evaluated by the coefficient of determination (R^2) and standard error (S.E.). The data on drying and thermal processing were analysed using Microsoft Excel (Microsoft Inc., USA).

3. Results and discussion

Watermelons of "*Sugar baby*" cultivar yielded 48.62% juice, 31.80% rind and 14.73% pomace (including seeds). The previous studies on watermelon reported 41.5–60% juice, 31–49.55% rind and 8.9–23.59% pomace (Shin et al. 1978; Crandall and Kesterson, 1981; Uddin and Nanjundaswamy, 1982; Hayoglu and Fenercioglu, 1990; Sogi, 2003). Values of various parameters were with range of values reported in the literature.

3.1. Physico-chemical analysis of watermelon pomace

Moisture, total soluble solids and ascorbic acid contents of watermelon pomace were found to be 91.47%, 6.18°B and 3.72 mg/100 g wb respectively. The crude fat and protein content of dried watermelon pomace were found to be 11.15% and 4.37% on dry basis (db) respectively. The pH and acidity of watermelon pomace were found to be 4.58% and 0.152% respectively. The reducing sugars and total sugars of fresh watermelon pomace were found to be 2.1% and 2.5% respectively. The colour values such as 'L', 'a' and 'b' of watermelon pomace were 22.05, 2.73 and 3.02 respectively.

The lycopene content of fresh watermelon pomace was found to be 12.20 mg/100 g (db) which was higher than lycopene in watermelon juice 4.51–5.32 mg lycopene/100 g fresh weight (Perkins-Veazie et al. 2001).

Sharma et al. (2008) reported total soluble solids, acidity, reducing sugars and total sugars of watermelon juice varied from 6.8–7.2°B, 0.06–0.09%, 3.47–3.78% to 5.22–5.29% wb respectively whereas the lycopene content of fresh watermelon juice was reported to be 4.403 mg/100 g db respectively. Arocho et al. (2012) estimated the moisture, pH, total soluble solids and lycopene of fresh watermelon pomace varied from 90.16–90.99%, 5.09–5.20, 8.4–9.7°B to 20–24 mg/100 g wb respectively. Hence the present results are in accordance with previous results.

3.2. Drying characteristics of watermelon pomace

The initial moisture content of watermelon pomace was found to be 925.66% (db). The moisture content was reduced to 6.57–8.90% (db) at 2–6 kg/m^2 feed rates for fluidized bed dryer and 6.87–11.36% (db) for cabinet dryer respectively. The moisture content decreases continuously with increase in the time period in all the temperature and the dryers indicating that drying of watermelon pomace takes place in the falling rate period (Figs. 1 and 2). Kaur et al. (2006) studied drying characteristics of peel isolated from tomato pomace in cabinet and fluidized bed dryer concluded that drying took place in falling rate period.

In fluidized-bed dryer, time for drying of watermelon pomace was 1.1 h and 2.1 h for feed rate of 2 and 6 kg/m^2 at 70 °C. In cabinet dryer, time for drying of watermelon pomace

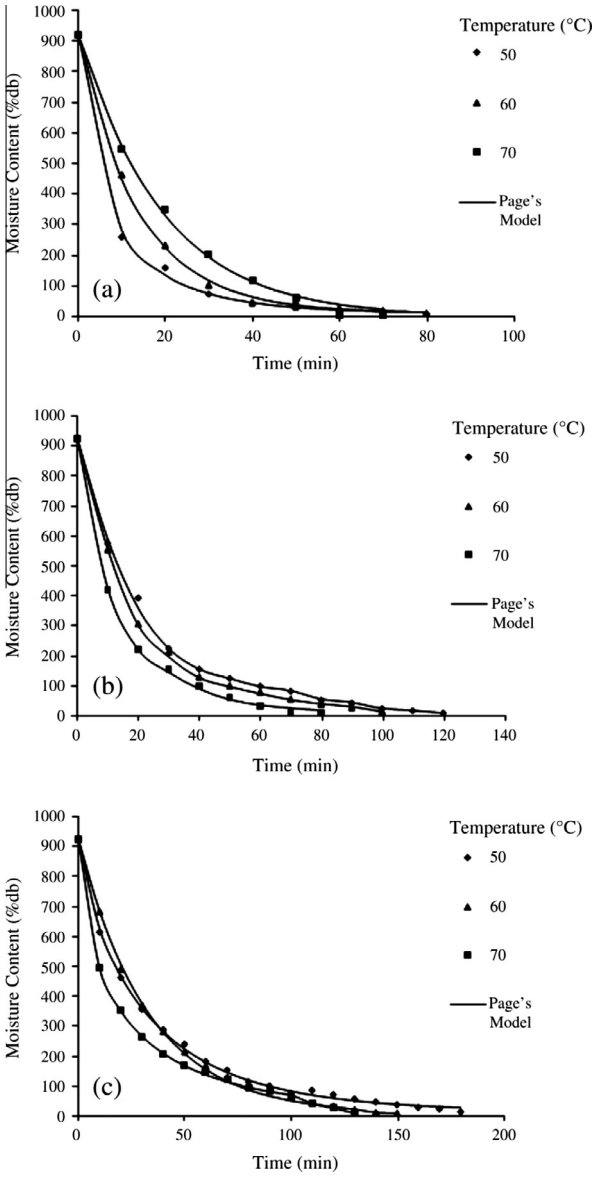

Figure 1 Drying curves of watermelon pomace dried in a fluidized bed dryer (a–c) with 2, 4 and 6 kg/m^2 tray load respectively at 50–70 °C.

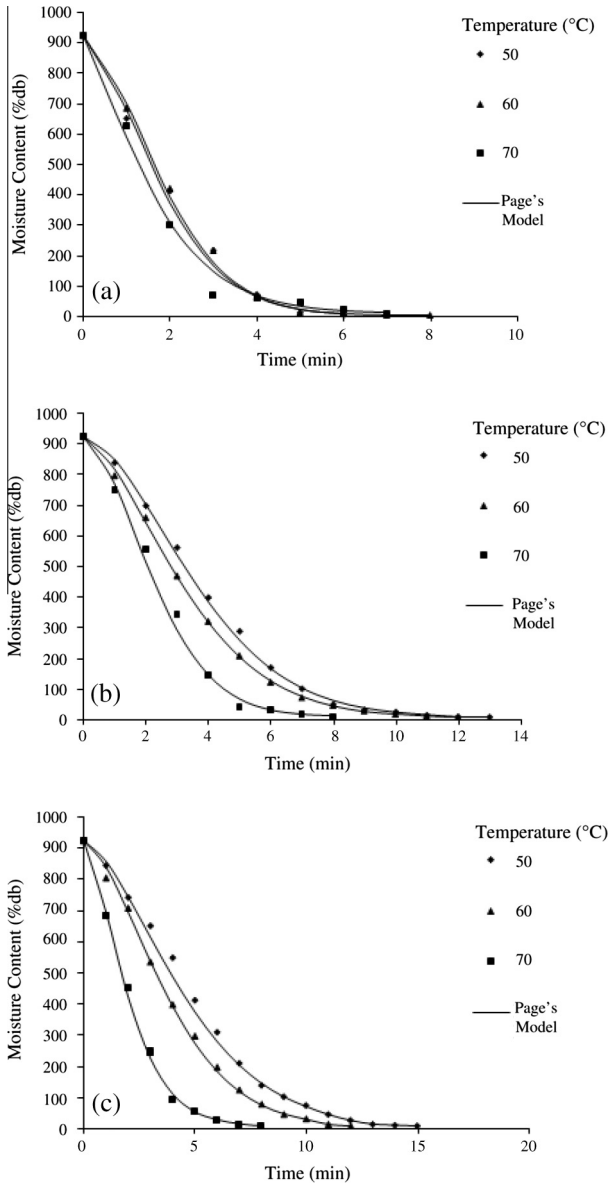

Figure 2 Drying curves of watermelon pomace dried in a cabinet dryer (a–c) with 2, 4 and 6 kg/m^2 tray load respectively at 50–70 °C.

was 7 and 8 h for feed rate of 2 and 6 kg/m^2 at 70 °C. Hence, fluidized-bed dryer took minimum time for drying followed by cabinet dryer. Previous results showed that a fluidized bed dryer was more efficient to dry tomato pulp than tray, freeze and cabinet dryer (Chawla et al. 2008).

3.3. Mathematical drying models

Various mathematical models such as Lewis, Henderson and Pabis, Logarithmic, Page and Wang & Singh were applied to the drying data of watermelon pomace. Out of these models, the Page's model was found to be best fit with higher value of R^2 0.989. Regression analysis was carried out using Page's model and coefficients were determined. The drying rate constant (k) varied from 0.098 to 0.446 1/h for fluidized bed dryer and from 0.086 to 0.456 1/h for cabinet dryer respectively. Dimensionless constant (n) varied from 0.625 to 1.077 and 1.292 to 1.681 for fluidized-bed dryer and cabinet dryer respectively. The reaction rate constant for lycopene loss in tomatoes quarters was in the range of 0.0780–0.4479 1/h and was significantly affected by drying air temperature (Demiray et al. 2013). Results revealed that drying rate constant (k) for watermelon pomace increased with increase in drying air temperature for both fluidized bed dryer and cabinet dryer respectively. This means as the drying air temperature increased, the drying time of watermelon pomace decreased. The Page's model adequately describes the drying behaviour of watermelon pomace over the range of temperature used in the study. The value of R^2 was found to be maximum in fluidized bed dryer i.e. 0.996 with minimum value of standard error i.e. 0.010.

3.4. Effect of temperature on drying rate constant

Arrhenius equation was used to show the dependence of drying rate constant on temperature for fluidized-bed and cabinet drying of watermelon pomace (Eq (7)). The activation energy obtained from the slope of plot for 'k' was varied from 27.43 to 30.61 and 16.31 to 35.39 kJ/mol for fluidized bed and cabinet dryer respectively. Results revealed that Arrhenius's equation (Eq. (7)) explained well the relationship between the drying air temperature and drying rate constant (k). Henry et al. (1998) found the activation energy of 19.8 kcal/mol for lycopene degradation during oxidative thermal treatment of carotenoids in oil system. Kaur et al. (2006) found the activation energy was 36.80 kJ/mol for cabinet dryer and 20.59 kJ/mol for fluidized bed dryer for tomato peel at 4 kg/m^2.

Akpinar and Toraman (2013) found the activation energy value of 19.3 kJ/mol during thin layer drying of ginger slices with temperature range of 40–70 °C and air velocity of 0.8–3 m/s. Falade et al. (2007) found the activation energy in the range of 5.09–32.77 kJ/mol during the osmotic dehydration of watermelon. Previous findings support the present results.

3.5. Degradation of lycopene during fluidized bed and cabinet drying

The lycopene content of watermelon pomace was found to be 12.20 mg/100 g. Retention of lycopene in watermelon pomace dried in fluidized-bed dried pomace varied from 5.67 to 9.86 mg/100 g (db) at 50–70 °C. In cabinet dried pomace, lycopene retention varied from 4.82 to 8.14 mg/100 g (db) at 50–70 °C (Table 1). The increase in time and temperature resulted in decrease in the retention of lycopene. Fluidized bed dryer retained higher lycopene level which might due to fact that in fluidized bed drying the hot air was supplied at high velocity and pomace was in the fluidizing action and maximum surface area was exposed to the hot air. Demiray et al. (2013) concluded that prolonged drying times increase the degradation rate of lycopene, β-carotene and ascorbic acid in tomatoes during hot air drying. The change in lycopene content in watermelon pomace during drying in fluidized bed dryer and cabinet dryer at 50–70 °C with feed rates of 2, 4 and 6 kg/m^2 is shown in Figs. 3 and 4. It was found the lycopene degrades at all the temperatures with different feed rates in both fluidized bed dryer and cabinet dryer. It was found that

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Table 1 Comparison of lycopene loss during drying and thermal degradation of watermelon pomace.

Drying system	Temperature (°C)	Feed rate (kg/m^2)	Time (h)	Lycopene retention during drying (mg/100 g) Experimental values	Lycopene loss during drying (%)	Lycopene retention during thermal treatment (mg/100 g)	Lycopene loss during thermal treatment (%)	Difference in lycopene loss (%) between drying and thermal treatment
Fluidized-bed dryer	50	2	1.3	9.88 ± 0.04	19.02	11.29 ± 0.08	7.46	11.56
		4	1.5	9.67 ± 0.03	20.74	11.18 ± 0.04	8.36	12.38
		6	1.7	9.11 ± 0.03	25.33	11.07 ± 0.01	9.26	16.07
	60	2	1.3	9.25 ± 0.05	24.18	11.10 ± 0.00	9.02	15.16
		4	1.4	8.64 ± 0.08	29.18	11.05 ± 0.02	9.42	19.75
		6	1.6	7.56 ± 0.10	38.03	10.95 ± 0.07	10.24	27.79
	70	2	1.0	6.79 ± 0.13	44.34	11.34 ± 0.11	7.05	37.29
		4	1.2	6.2 ± 0.06	49.18	11.08 ± 0.06	9.18	40.00
		6	1.3	5.67 ± 0.09	53.52	10.89 ± 0.07	10.74	42.78
Cabinet dryer	50	2	6	8.14 ± 0.07	33.28	10.16 ± 0.02	16.72	16.56
		4	10	7.43 ± 0.04	39.10	9.11 ± 0.03	25.33	13.77
		6	11	7.13 ± 0.08	41.56	8.88 ± 0.05	27.21	14.35
	60	2	5	7.22 ± 0.14	40.82	9.85 ± 0.09	19.26	21.56
		4	9	6.87 ± 0.03	43.69	8.19 ± 0.07	32.87	10.82
		6	10	5.87 ± 0.02	51.89	7.58 ± 0.02	37.87	14.02
	70	2	5	5.44 ± 0.06	55.41	8.78 ± 0.05	28.03	27.38
		4	7	5.23 ± 0.01	57.13	7.31 ± 0.11	40.08	17.05
		6	8	4.81 ± 0.10	60.57	6.92 ± 0.07	43.28	17.29

there was close relationship between the experimental and predicted values of lycopene in both fluidized and cabinet dried watermelon pomace. Goula et al. (2006) predicted the lycopene degradation during drying of tomato pulp and concluded that there was a close agreement between the experimental and predicted values of lycopene loss during the tomato pulp concentration confirming the validity of the proposed model for simple drying process whereas for the spray drying process, the product was converted in the form of droplets and hence larger surface area exposed to air enhanced lycopene oxidation.

The aerobic degradation was highly responsible for degradation of lycopene in fluidized bed dryer in less time. The pigments as the antioxidants may selectively become oxidized and in turn lose their characteristics colour and provitamin A function especially in case of severe oxidation (Henry et al. 1998). Oxidation is undesirable because it leads to lycopene degradation and a concomitant loss of its health related properties (Rodriguez-Amaya and Kimura, 2004). Cole and Kapur (1957) observed 25% apparent lycopene loss in the presence of oxygen and only 5–8% in the presence of carbon dioxide when heating the tomato pulp at 100 °C for 2 h.

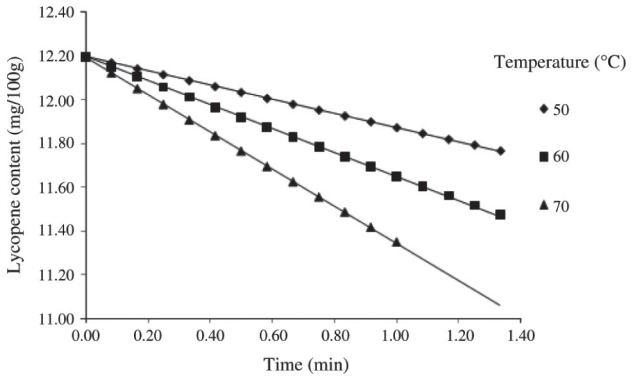
3.6. Degradation of lycopene during thermal treatment

The lycopene decreased from 12.20 to 10.1 mg/100 g at 50 °C and 2.79 mg/100 g at 90 °C after 7 h of heating. The degradation rate constant for lycopene was 0.027 1/h at 50 °C which increased to 0.204 1/h at 90 °C. The reaction rate constant for lycopene degradation during oxidative thermal treatment of lycopene in oil system was found to be 0.109–0.518 1/h at temperatures 75–95 °C (Henry et al. 1998). The degradation of lycopene occurs due to high temperature. The graph between predicted values and observed values of lycopene extracted from watermelon pomace is shown in Fig 5. The R^2 for lycopene ranged between 0.898 and 0.988. Sharma et al. (2008) reported the lycopene content of fresh watermelon juice to 4.403 mg/100 g which decreased to 2.8 mg/100 g after 5 h of heating at 50 °C and decreased to 0.82 mg/100 g after 5 h of heating at 90 °C. The degradation rate constant was reported to vary from 0.0874 1/h to 0.2878 1/h and R^2 ranged from 0.937 to 0.996. Lee and Chen (2002) studied the stability of lycopene during heating and illumination and also concluded that the degradation of lycopene fitted the first order model with degradation rate and increased with increasing temperature.

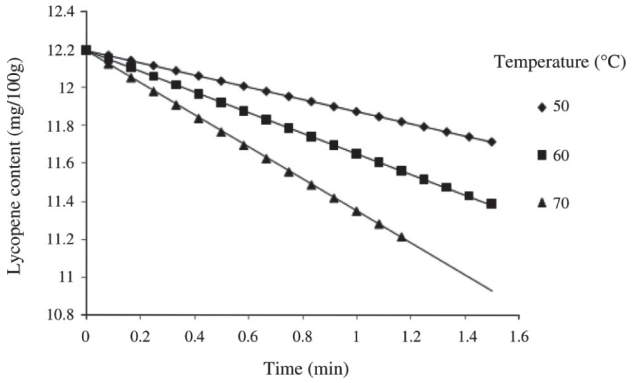
3.7. Lycopene retention during thermal and drying treatment

The relationship between the lycopene content, pomace temperature during thermal degradation and drying methods was established. The lycopene content degraded continuously as the product temperature increased. The degradation kinetic model was used to estimate the predicted values of lycopene in different drying methods. The results concluded the significant relationship between the observed value and predicted value of lycopene with coefficient of determination of 0.883 in fluidized bed drying and 0.887 in cabinet drying. The results revealed that lycopene loss during fluidized bed drying and cabinet drying of watermelon pomace was in the range of 19.02–53.52% and 33.28–60.57% where lesser range of lycopene loss i.e. 7.46–43.28% was observed during thermal treatment of watermelon pomace at different temperatures 50–70 °C and feed rates 2–6 kg/m^2 (Table 1).

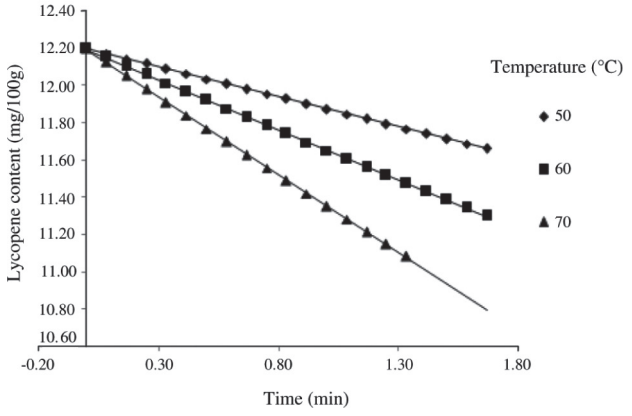
The lycopene retention at different time intervals during drying and thermal degradation was analysed. It was found that in thermal degradation of watermelon pomace the lycopene retention was more as compared to drying methods that might be due to the fact that higher degradation of lycopene occurs in drying methods due to aeration. Shi et al. (1999) concluded that conventional air drying decreases lycopene retention greatly in tomato samples due to influence of heat and



(a) 2kg/m ^{2} Feed Rate

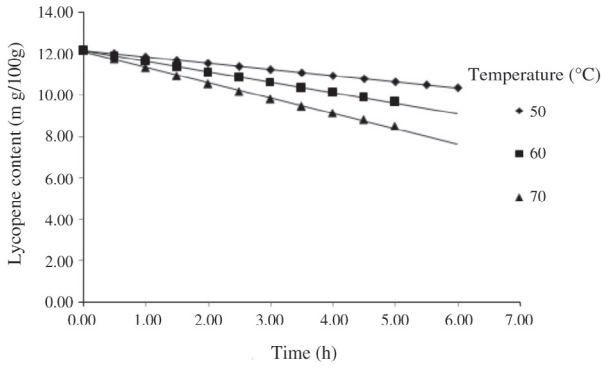


(b) 4kg/m^2 Feed Rate

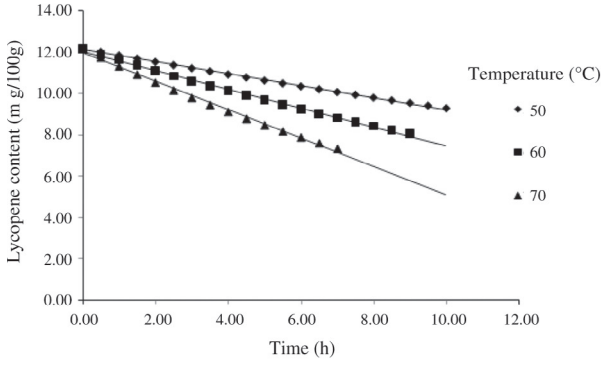


(c) 6kg/m^2 Feed Rate

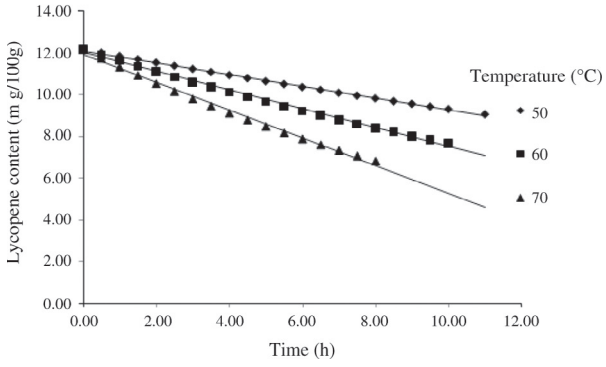
Figure 3 Change in lycopene content during drying of watermelon pomace in fluidized bed dryer at 2, 4 and 6 kg/m^2 feed rate (a–c).



(a) 2kg/m^2 Feed Rate



(b) 4kg/m^2 Feed Rate



(c) 6 kg/m^2 Feed Rate

Figure 4 Change in lycopene content during drying of watermelon pomace in cabinet dryer at 2, 4 and 6 kg/m^2 feed rate (a–c).

oxygen and in air drying isomerization and oxidation were the key factors affected the decrease of total lycopene content. The rate of degradation is increased by exposure to high temperatures, light and oxygen and low moisture content resulting in isomerization from *trans*- to *cis*-forms and from auto oxidation of *trans*-lycopene (Giovanelli and Paradiso, 2002). Suvarnakuta et al. (2005) studied β-carotene degradation in carrot undergoing different drying processes and revealed that hot air drying caused more aerobic degradation of β-carotene compared with low pressure superheated steam drying and

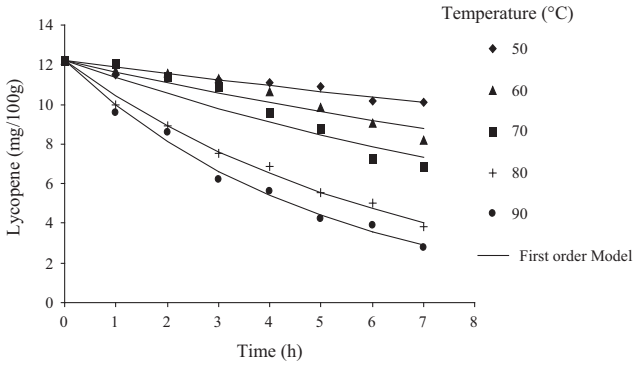


Figure 5 Degradation kinetics of lycopene in watermelon pomace during thermal treatment.

vacuum drying and level of oxidation was the major cause of β-carotene degradation in carrots.

4. Conclusion

Watermelon pomace being the concentrated source of lycopene can be used in dried form to obtain the value added products. Drying behaviour of watermelon pomace followed the falling rate period pattern and adequately described by Page's model over the range of temperatures and tray loads used. Dehydration carried out in fluidized bed and cabinet dryer makes the product less red as compared to fresh pomace sample. Drying by cabinet dryer gave poor results for the lycopene content as compared to fluidized bed drying. Lower degradation of lycopene occurs in fluidized bed dryer as compared to cabinet dryer. Higher lycopene loss was obtained during dehydration as compared to thermal degradation of watermelon pomace which might be due to the fact that higher degradation of lycopene occurs by aeration in drying process. Dried pomace with higher shelf life containing high value of lycopene can be utilized as a potential food ingredient to increase the nutraceutical and aesthetic value of food products.

Conflict of interest

There is no conflict of interest.

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